Observational Study on Landslide Mechanism in the Area of Crystalline Schist (Part 1) -An Example of Propagation of Rankine State-

AUTHOR(S):

SUEMINE, Akira

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By Akira SUEMINE

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Abstract

Propagation of Rankine state was analyzed on the basis of the observation with a high time-resolution of surface and subsurface deformations in a crystalline schist landslide area. The differences in the onset time of deformation at different sites revealed the direction and speed of the propagation. Vertical propagation from the slip surface to the ground surface was clarified by the examination of internal strain at different depths. The records of the extensometer set up over a head cliff and those of the internal strain meters near the depth of the slip surface suggested the duration of the deformation.

1. Introduction

Various instruments at many landslide areas have recorded landslide phenomena. But the density of these instruments and time accuracy have been rough, therefore very little has been stated about landslide mechanism. The main subjects of observation have consisted of some of the determination of landslide boundary, the depth of slip surface, the contraction and extension region, the landslide direction, the displacement magnitude, the prediction of landslide occurrence time and the judgement of counter measures. But there was a report of rupture propagation speed in a tertiary type landslide by means of observations of some internal strain meters every few days.[1] Landslide in crystalline schist landslide area in Japan has not been observed in detail. Hence this type of landslide is not clearly determinable by instruments. There were few reports on landslide mechanisms in this area.

Figure 1 shows a model of a landslide mechanism. Many physical quantities must be determined to make this mechanism clear. These consist of the time and place of rupture, the direction and velocity of its propagation, the magnitude of subsurface displacement velocity, the dependence of displacement upon the place, the magnitude of rise time, the vertical propagation velocity from the slip surface to the ground surface and the dimension of slip surface. If these are clarified, prevention of landslide would become easy.

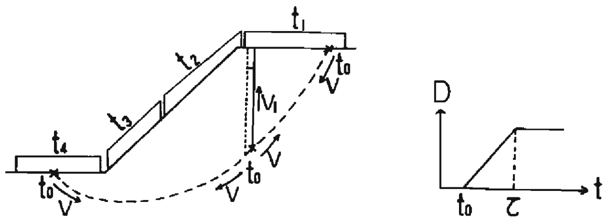


Fig. 1. Schematic model of landslide mechanism. t_0 is the time of rupture occurrence. t_1, t_2, t_3 and t_4 are the time when each extensometer records the displacement at first. V_1 and V are the vertical speed and horizontal speed of propagation of displacement. D is the magnitude of displacement at slip surface and τ is a rise time.

The author and his colleagues have observed the landslide phenomena to make clear these physical quantities at several landslide areas in Tokushima Prefecture, Shikoku, Japan during the past few years. This paper describes some characteristics of these physical quantities in crystalline schist landslide areas.

2. Method of observation

Ground surface movements were observed by means of extensometers with a magnification of 5 x. Two piles hammered about 0.7 m deep into the ground are provided at the points to be measured. Between these two points a super-invar wire was stretched, one end of which is fixed on one of the piles, while the other is connected to a recorder installed on the pile. The speed of paper feed is 4 mm per hour. Subsurface displacements were observed by internal strain meters. These are made in such a way that the strain gauges, the factor of which are about two, are attached to a vinyl chloride pipe (PVC) at every 1 meter interval. These are inserted into boreholes. The vacant space between these instruments and the boreholes was filled with sand. Hence, it is believed that these instruments record the ground deformation faithfully. We recorded the internal strain on digital magnetic tapes at some landslide areas, while using automatic digital strain meter at other areas. These measuring systems include a high precision timer, so accurate observation of time could be carried out.

3. Results and discussion

3.1 Nishiikawa landslide area

Nishiikawa landslide area in Tokushima Prefecture is situated in the Sanbagawa metamorphic belt and is occupied by alternating argillaceous schist and green schist. The bed strikes N74°E to N95°E and dips 20°N to 30°N. Because of artificial cutting of the slope to establish a woodworking plant, a landslide took place in November 1973. After this, heavy rains are accompanied by landslide movements. When the amount of rainfall came to 285 mm from Jun. 26 to Jul. 4, 1979, a landslide occurred.

Figure 2 shows the location of instruments. **Figure 3** illustrates a record of internal strain gauges at site No. 2 in **Fig. 2.** Internal strains were mainly recorded at intervals of ten minutes. In a part of the latter half of

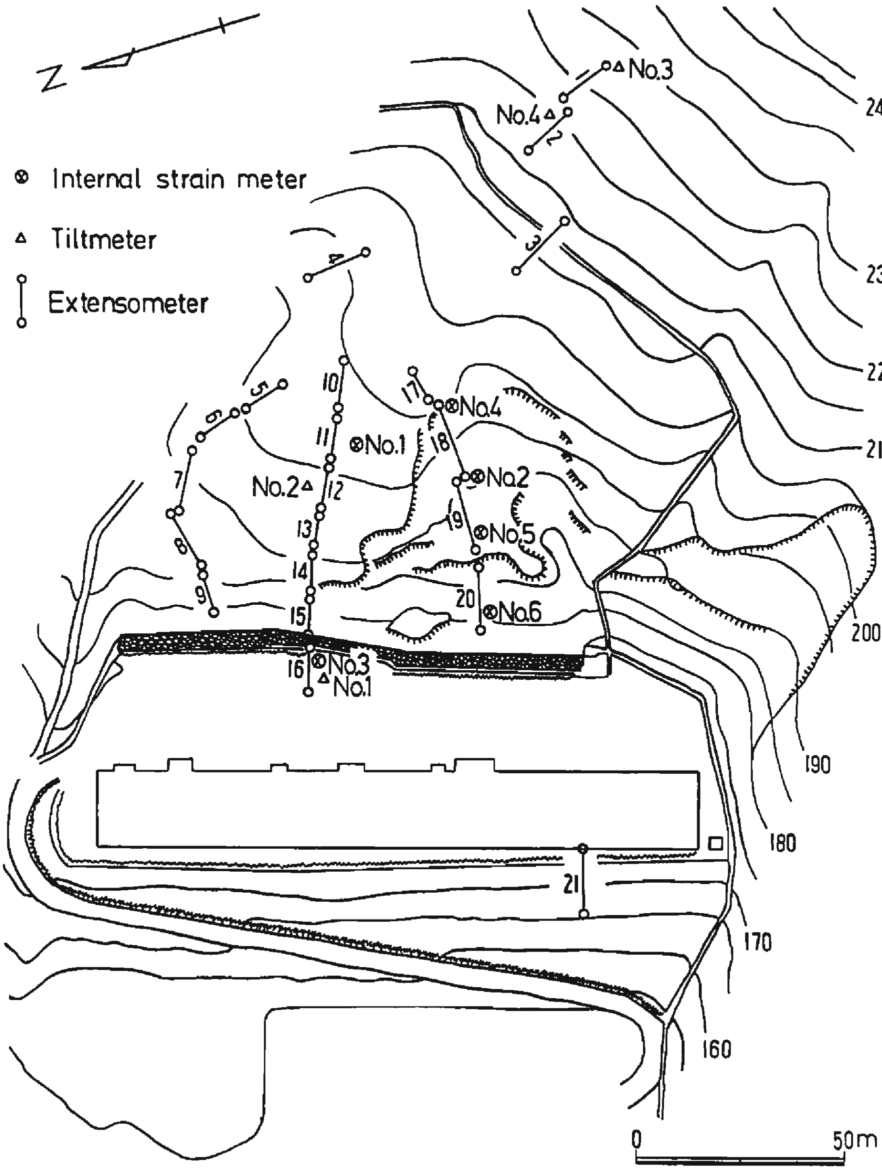


Fig. 2. Location of instruments at Nishiikawa landslide area.

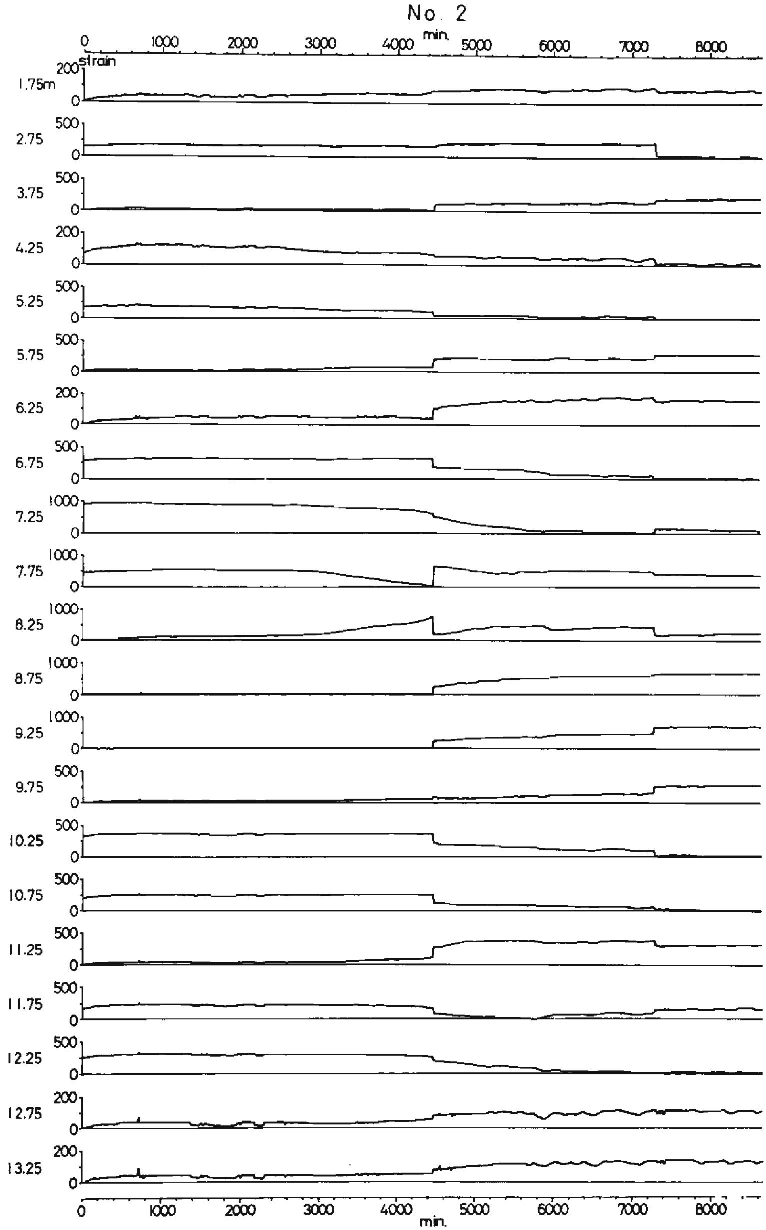


Fig. 3. Examples of the records of internal strain at site No. 2 in **Fig. 2** from Jun. 27 to Jul. 3, 1979; unit micro strain.

observation, the interval was changed to twenty minutes or an hour. Internal strain records at the depth of 7.25 m, 7,75 m and 8.25 m show two kinds of strain change. One is continuous change in time (creeping phenomenon), the other is an abrupt change (brittle fracture phenomenon). These records revealed that this landslide area had both creeping and brittle fracture phenomenon.

These instruments need to be checked up, because the curvature of PVC was not ascertained after installing them. At that time, a strain meter of insertion type was used, which was developed by Shima and Takeuchi.[2] An error induced by inserting this instrument into PVC is at most 200 micro strains. **Figure 4** shows that no displacement was observed on Jun. 2, 1979 when one month passed after boring. The measurement on Jul. 25, 1979 made it clear that slip surface existed at about 8 m depth. Calibration of this instrument indicated that sensitivity did not change. From this, it is certain that PVC curved at this depth. The direction of creeping phenomenon at 7.75 m and 8.25 m depth was opposite that of the abrupt phenomenon. Consequently, the radius of curvature of PVC became greater. This is the reason why the maguitude did not take a large value.

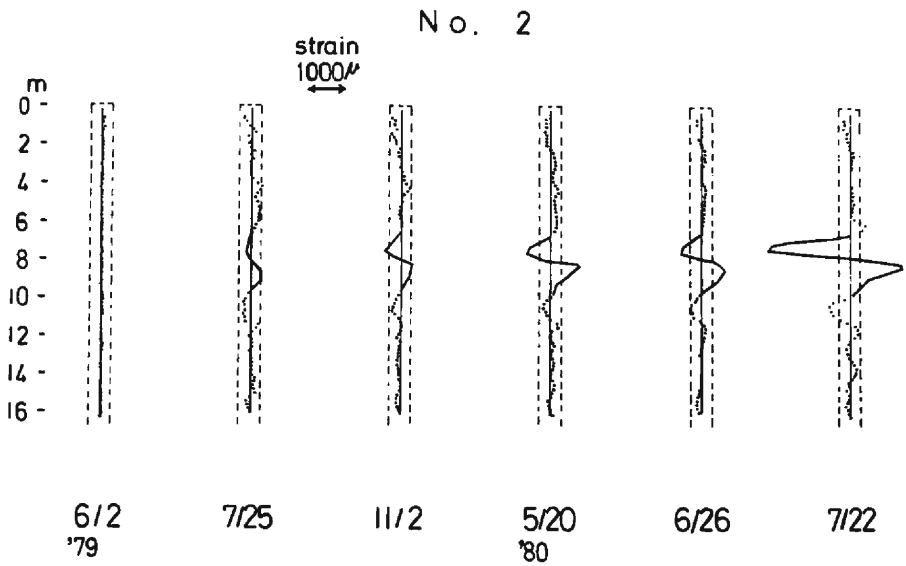


Fig. 4. Values of the strain meter of insertion type at site No. 2 in **Fig. 2**; unit micro strain.

The abrupt change, which was closely connected with brittle fracture, simultaneously occurred at all gauges shallower than 13.25 m. The place of rupture occurrence, its propagation direction and velocity could not be determined. But on the basis of the above mentioned observations, it was suggested that the velocity was more than 1 m per minute.

The onset time of creeping landslide was determined as follows. The irregular interval data were interpolated by spline function with three degrees, which was programmed by Saito,[3] and were converted to data of ten minutes intervals. A Gaussian window which was programmed by Tanaka[4] was used for a low-pass filter. A study of Ishikawa and Miyatake[5] made it clear that Wiener's predictive filter could determine the onset time of long period phenomena. This filter was used to determine the onset time of creeping phenomenon. The onset time was regarded as the time when the strain rate changed. Differential coefficients, which were strain rate, were computed by numerical calculation. Input data for Wiener's predictive filter were differential coefficients of the data convolved by the Gaussian window. The number of the data for calculating the autocorrelation function was 100. The number of Wiener's predictive filter, which was computed from this autocorrelation function, was ten. This filter predicted a forward value which was a value after ten minutes. The occurrence time of creeping landslide was regarded as the time when the difference between the datum and predicted value had shown a value two times as large as the variance of the difference between a hundred previous observed predicted values. **Table 1** shows the onset time. This filter had no phase shift theoretically, but the error of onset time might have been ten minutes, one step of calculation, on account of some approximation of the computer.

Table 1. List of onset time at site No. 2 in **Fig. 2**. A letter enclosed within a circle is an irregular number which indicates the state of strain rate, + and − indicate the increment and decrement of differential coefficient and the number in parenthesis indicates a maximum of absolute value of differential coefficient.

	6/28		6/29	6/30			
7.25m			15:52 ②−	7:32 ②−	8:42 ④−	10:22 ③−	12:12 ⑦−(−1.9)
7.75m	10:12 ⑥−	15:02 ③−		9:52 ⑬−			12:12 ⑧+(9)
8.25m	8:32 ③+	15:12 ②+		9:02 ⑦+	10:42 ⑦+		12:22 ⑦−(−9)
8.75m	8:12 ②+						12:12 ⑧+(4.5)

Table 1 shows the time when both creeping and abrupt landslide occurred. First the creeping landslide occurred in the neighbourhood of 8.25 m and 8.75 m depth at 8:32 and 8:12 on Jun. 28, 1979, respectively. Secondly it occurred near 7.75 m depth at 10:12 on Jun. 28, 1979. Finally, an abrupt landslide occurred at 12:12 on Jun. 30, 1979 at all depths. From this reason, this landslide is considered to be a kind of creep fracture. The main slip surface existed near 8 m depth, since the change of differential coefficient of 7.75 m was opposite to that of 8.25 m and these absolute values at abrupt landslide were the largest. **Figure 5** suggests a schematic model near slip

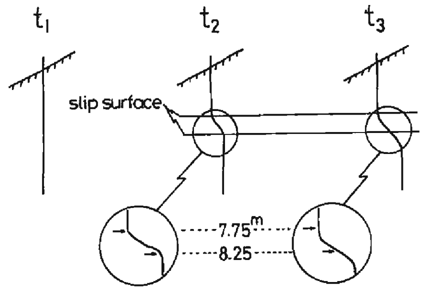


Fig. 5. Schematic model near slip surface.

surface which qualitatively explains the above mentioned fact. The slip surface of the creeping landslide exists between 7.75 m and 8.25 m, for the reason that the changes of differential coefficients were different at these depths. The slip surface of abrupt landslide exists deeper than the above mentioned one, since the sense of abrupt phenomenon was opposite to that of the creeping one and the magnitude of these two kinds of landslide was almost equal. PVC is convex at 7.75 m depth and is concave at 8.25 m depth at the creeping landslide, and this pipe straightens at the abrupt landslide at these depths on account of two slip surfaces. This expectation corresponds with the observa-

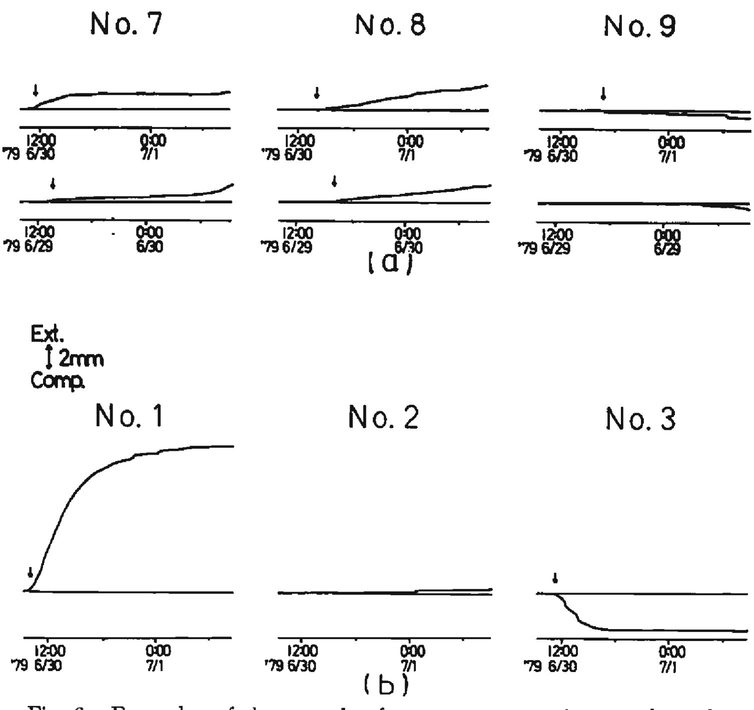


Fig. 6. Examples of the records of extensometers. Arrows show the onset time of displacement.

tions. Such phenomenon, where a failure zone (slip surface) shifts from one place to another can be observed only when both time and depth are very accurately obtained. This is a new physical concept in landslide mechanism.

The landslide mechanism at the upper part of the slope is explained first. Extensometers No. 1, No. 2 and No. 3 were set up at the upper part of the slope and No. 1 was set up over a head cliff (see **Fig. 1**). **Figure 6** shows that No. 1 recorded a strain of extension, No. 2 underwent a few strains of

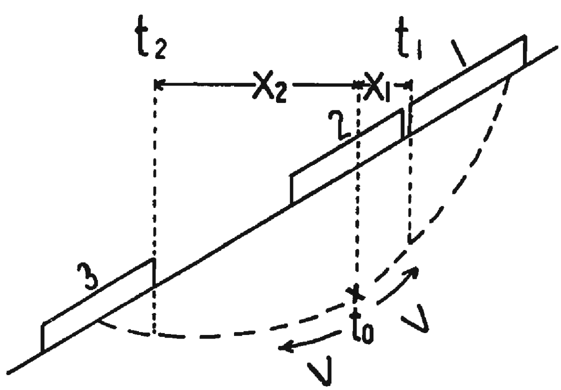
Table 2. List of rupture velocity at Nishiikawa landslide area.

Extensometer	Onset time	Phase	Mean rupture velocity
No. 1	6/29 12:27	ext.	4.3m/h (bi-lateral)
No. 3	6/29 13:51	comp.	
No. 1	6/30 10:11	ext.	3.6m/h (bi-lateral)
No. 3	6/30 11:50	comp.	
No. 13	6/27 12:35	ext.	0.26m/h (uni-lateral)
No. 14	6/27 13:56	comp.	
No. 15	6/29 14:25	comp.	10.66m/h
No. 16	6/29 15:52	comp.	
No. 15	6/30 3:48	comp.	31.97m/h
No. 16	6/30 4:17	comp.	
No. 15	6/30 11:19	comp.	8.66m/h
No. 16	6/30 13:06	comp.	
No. 15	7/1 8:17	comp.	46.35m/h
No. 16	7/1 8:37	comp.	

extension and No. 3 underwent contraction on Jun. 30, 1979. The record of these extensometers was assumed to indicate a chain of landslides. These observations indicate the place where a rupture of a landslide occurred, the velocity of rupture propagation and the length of rise time—landslide continuation. The time when a displacement on recording paper reached 0.5 mm was regarded as the onset time. The speed of paper feed was 4 mm per hour, hence time resolution became about one eighth of an hour. A time lag greater than one eighth of an hour was regarded as a significant one. **Table 2** shows the onset time. But the strain observed by the extensometer of No. 2 was much smaller than that of No. 1 and No. 3, and it appeared that the area of No. 2 did not produce a strain. Excepting this onset time, known quantities were the length of the spans of extensometers, the length between extensometers, and the sense of strain.

Since this area was not bored, the depth of slip surface was not known. But it was assumed that it was within a few meters with strict regard for topography. The vertical velocity of propagation of subsurface displacement from slip surface to ground surface was more than 1 m per minute according to the observations of internal strain meters. The time lag for the propagation of a strain to the ground surface was within a few minutes regardless of the depth of slip surface. This time lag was neglected as a first approximation, because the observed time lag was more than one hour. So, it was decided that the time when extensometer recorded a displacement was equal to the time when the displacement at a slip surface occurred.

The left half of **Fig. 7** indicates a model of a landslide mechanism which explains some observed quantities qualitatively. If a rupture had occurred at a head cliff and had been propagated to the lower slope, first No. 1 would



$$t_0 + \frac{X_1}{V} = t_1$$

$$t_0 + \frac{X_2}{V} = t_2$$

$$\therefore V = \frac{X_2 - X_1}{t_2 - t_1}$$

Fig. 7. Model of landslide mechanism at the upper slope. t_0 is the time of rupture occurrence. t_1 and t_2 are the time when No. 1 and No. 3 record the displacement at first. X_1 and X_2 are the length between the place of rupture occurrence and extensometer. V is the mean rupture velocity.

have recorded a strain of extension, secondly No. 2 would have recorded that of contraction and next that of extension, and thirdly, No. 3 would have recorded that of contraction. Actually, first No. 1 recorded a strain of extension and No. 2 showed few strains, secondly No. 3 showed contraction. To explain both the lag of onset time and the sense of strain, a rupture need occur at the middle area of No. 2 and be bilaterally propagated to both ends of the extensometer. The displacements of the two ends of No. 2 are almost equal, therefore it does not record a strain. First the lower pile of No. 1 moves to the lower part of the slope, and it records a strain of extension. Secondly the upper pile of No. 3, which is separated from No. 2, moves to the lower part of the slope, it records a strain of contraction. This explanation corresponds with observations.

In this case the onset time is given by

$$t_1 = t_0 + X_1/V$$

$$t_2 = t_0 + X_2/V$$

where t_0 is the time of rupture occurrence; t_1 and t_2 are the time when No. 1 and No. 3 record the displacement at first; X_1 and X_2 are the length between the place of rupture occurrence and extensometer, and V is the mean rupture velocity. V is given by eliminating t_0 from two equations

$$V = (X_1 - X_2)/(t_1 - t_2).$$

(see the right half of **Fig. 7**). In the same manner as mentioned above, mean rupture velocity at a slip surface in the lower part of a slope was determined. **Table 2** shows these velocities.

The outline of the discussion about mean rupture velocities is as follows. In the upper landslide slope, the rupture occurred at the middle part of the slope and was propagated bilaterally. The velocity was a few meters per hour. In the lower landslide slope, the place of rupture occurrence could not be found out, because only two extensometers recorded the landslide movements. But the mean rupture velocity was between about 10 m and 50 m per hour.

No. 1 was set up over a head cliff, so an upper pile set up above it was an immovable point and a lower pile moved. **Figure 6** shows that the change of strain at No. 1 finished after somewhat over ten hours. It was found out that the rise time of displacement was somewhat over ten hours in this area at this time.

The observations of No. 7, No. 8 and No. 9 shown in **Fig. 6** present an interesting problem; how much does the displacement depend on place. No. 7 installed uppermost among this group recorded a strain of extension at

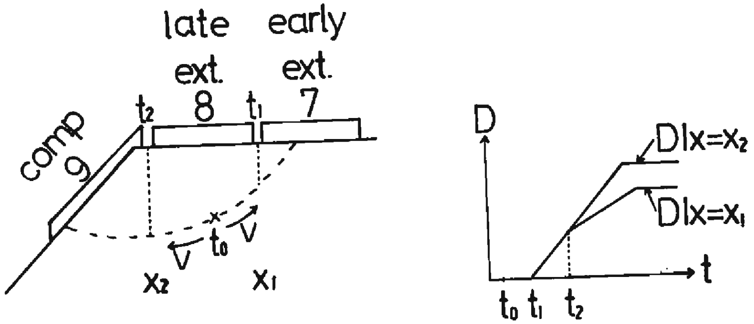


Fig. 8. Model of landslide mechanism at the lower slope. t_0 and t_1 are the time of rupture occurrence and the time when No. 7 and No. 8 record the displacement at first, respectively. t_2 is the time when the displacements of both ends at No. 8 are different. $D|_{x=x_1}$ and $D|_{x=x_2}$ are the displacement at x_1 and x_2, respectively.

12:18 on Jun. 29 and 11:27 on Jun. 30, 1979, and No. 8 recorded that of extension at 16:20 on Jun. 29 and 14:05 on Jun. 30, 1979. If a rupture had occurred in the area of No. 7 and had been propagated bilaterally, No. 7 would have recorded a strain of extension and No. 8 would have recoded that of contraction. If a rupture had occurred at the lower pile of No. 8 and had been propagated bilaterally, first No. 8 would have recorded a strain of extension and secondly No. 7 would have recorded that of extension. To explain these observations qualitatively, the left half of **Fig. 8** shows a model. A rupture occurs at the middle part of No. 8 and is propagated bilaterally. When it reaches the piles, the displacements are equal for several hours. No. 8 records no strain and No. 7 does that of extension. After a while, they differ and No. 8 records that of extension. Because a dip at No. 9 is steeply transformed, it records few strains. The displacement at upper pile of No. 9 was horizontal and the length between upper pile and lower pile of No. 9 did not change too much. If we view the matter from this angle, observations will be able to be explained.

3.2 Irahara landslide area

Irahara landslide area in Tokushima Prefecture is situated in the Sanbagawa metamorphic belt and is underlained mainly by argillaceous schist and partly by green schist and quartz schist. The bedrock is estimated to be from 16 m to 45 m deep by boring and seismic prospecting. From Jul. 1 to Jul. 2, 1980, the amount of rainfall came to 87.0 mm; 168.0 mm from Jul. 7 to Jul. 14, 1980; 570.5 mm from Sep. 6 to Sep. 11, 1980 and 191.5 mm from Oct. 12 to Oct. 14, 1980, when a landslide occurred.

Figure 9 shows the location of instruments. Internal strains were recorded at an interval of one minute. **Figure 10** illustrates a variation of

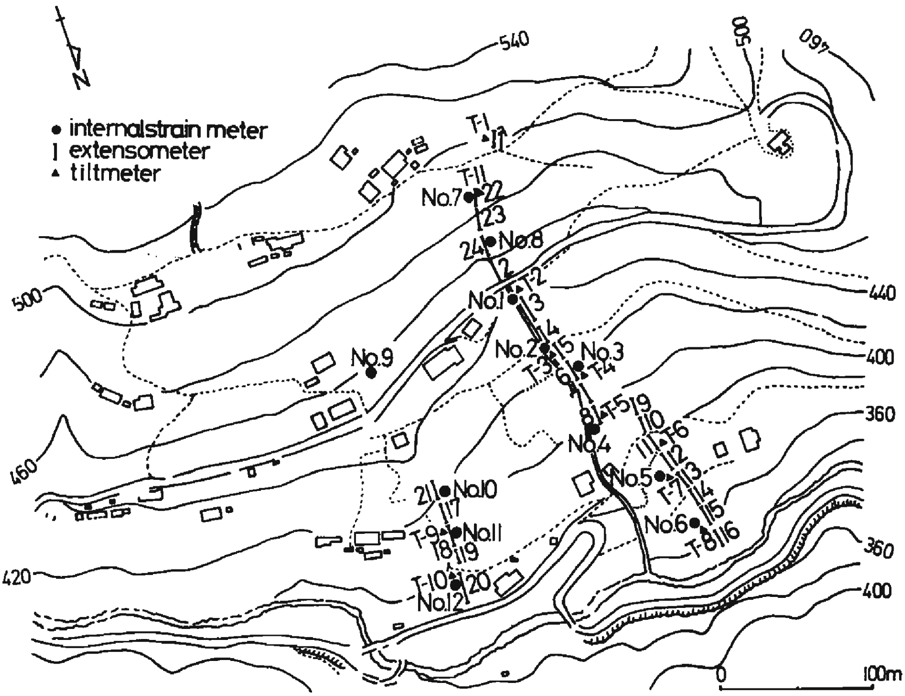


Fig. 9. Location of instruments at Irahara landslide area.

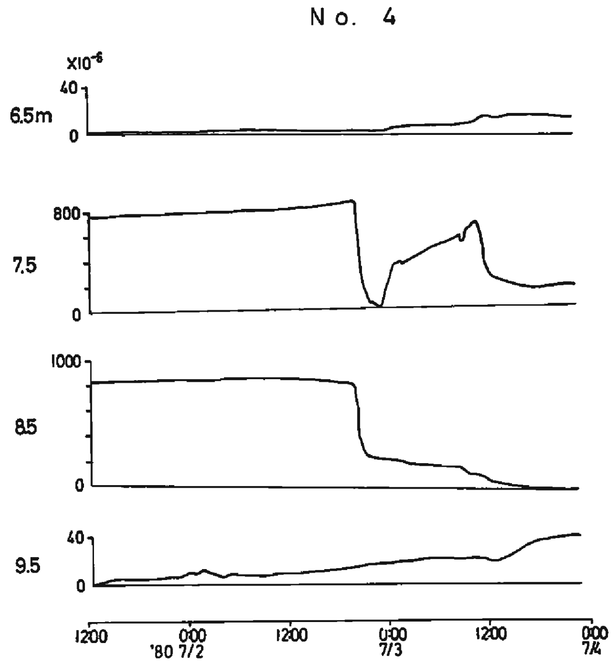


Fig. 10. Examples of the records of internal strain at site No. 4 in **Fig. 9** from 12:30 on Jul. 1 to 22:27 on Jul. 3, 1980; unit micro strain.

internal strain at internal strain meter No.4 in **Fig. 9**. The internal strain gauges at 7.5 m depth recorded about 800 micro strains from 20:00 to 23:00 on Jul. 2, 1980 and that of 8.0 m depth recorded about 600 micro strains from 20:00 to 21:30 on Jul. 2, 1980. Internal strain gauges at 6.5 m and 9.5 m depth recorded few strains. A strain meter of insertion type, as was stated previously, was used to check these displacements (see **Fig. 11**). The amplitude at about 7 m, which was almost equal to the depth of slip surface, was about 3,100 micro strains on Nov. 13, 1979, Dec. 11, 1979 and May 23, 1980. This reached about 5,000 micro strains on Jul. 23, 1980. It was certain that PVC was bent at this depth. The displacements at 7.5 m and 8.5 m were true and the rise time, which is defined as the time when the displacement continued, was about three hours at this time.

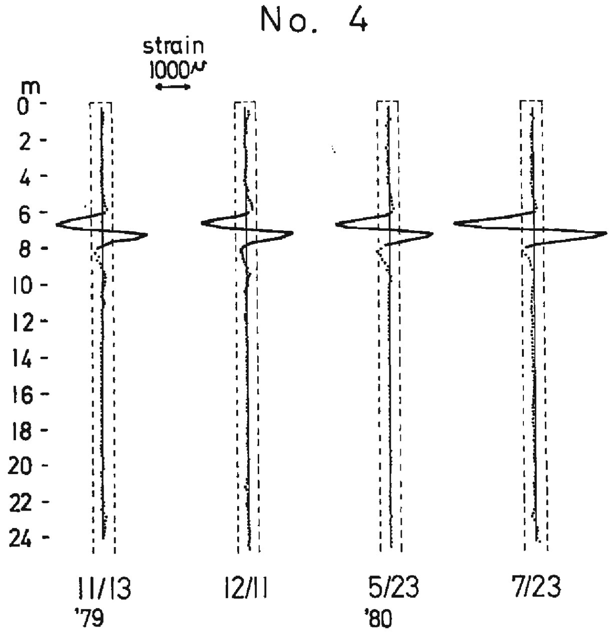


Fig. 11. Values of the strain meter of insertion type at site No. 4 in **Fig. 9**; unit micro strain.

Figure 12 shows the observations of internal strain meter No. 2 in **Fig. 9** from 7:00 on Jul. 12 to 4:00 on Jul. 14, 1980. An abrupt change which was closely connected with brittle fracture simultaneously occurred at all gauges at 5:09 and 21:59 on Jul. 13, 1980. It was certain that the vertical propagation velocity of brittle fracture was more than 5 m per minute. The gauges at 11.5 m and 12.5 m depth observed interesting phenomena. At 5:09 on Jul. 13, 1980, the strain of 11.5 m increased 20 micro strains and that of 12.5 m decreased 147 micro strains. After this, the gauges at 11.5 m depth

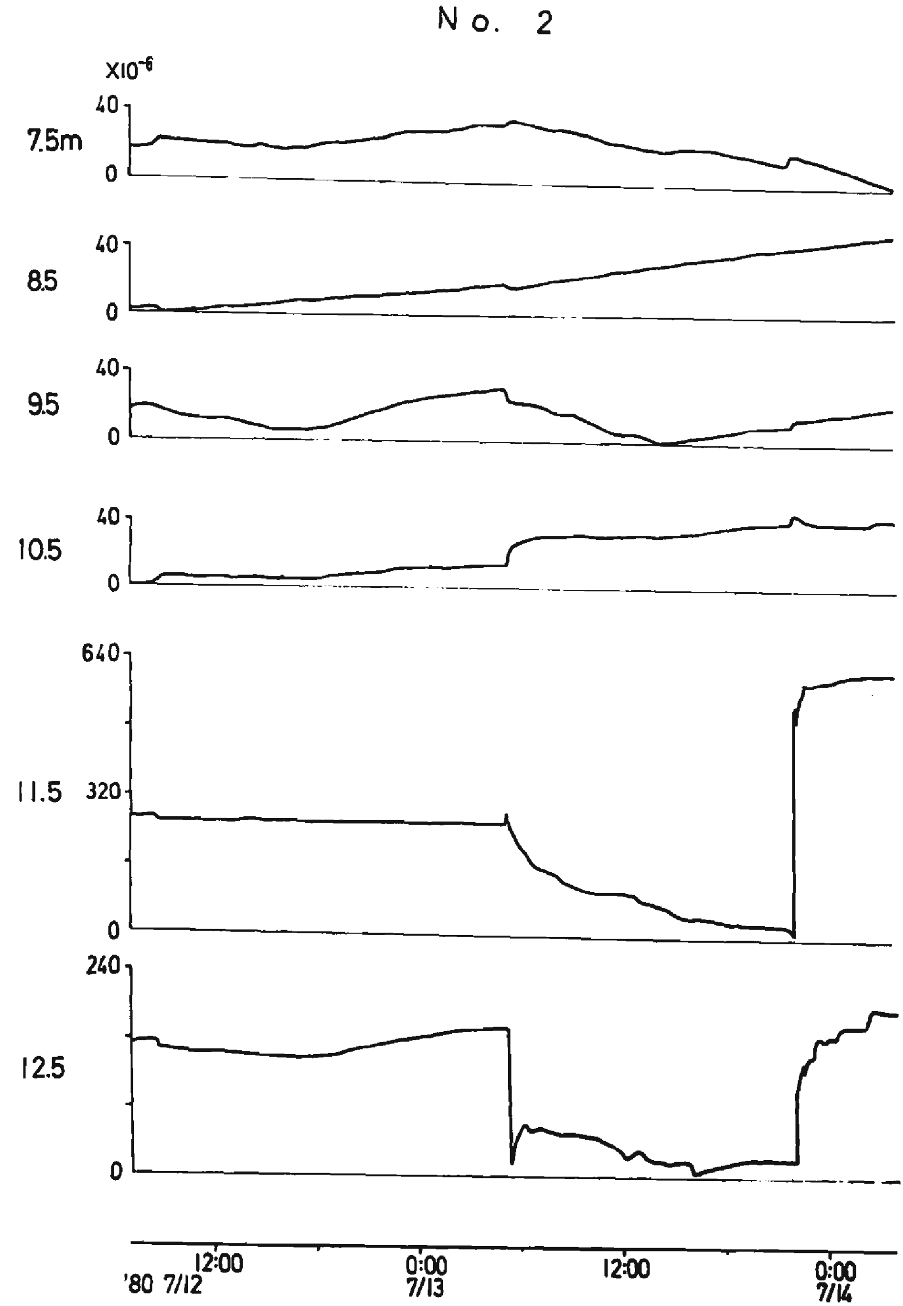


Fig. 12. Examples of the records of internal strain at site No. 2 in **Fig. 9** from 7:00 on Jul. 12 to 4:00 on Jul. 14, 1980; unit micro strain.

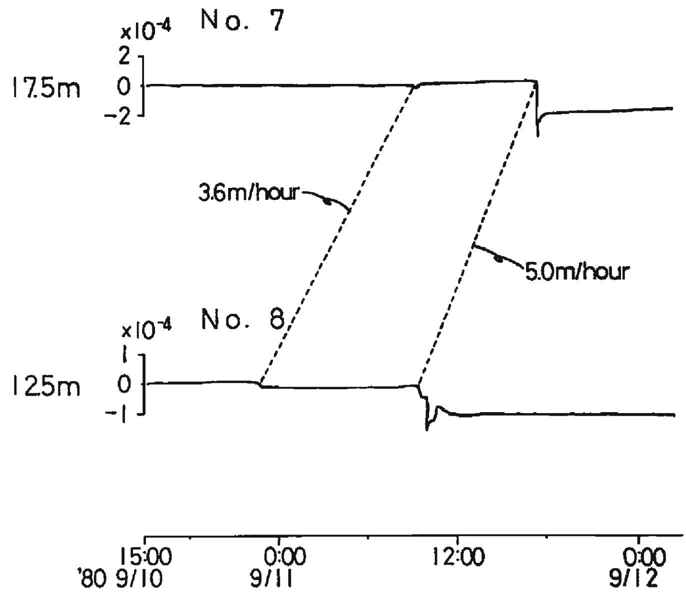


Fig. 13(a). Examples of the records of internal strain at site No. 7 and No. 8 in **Fig. 9** from Sep. 10 to Sep. 12, 1980; unit micro strain.

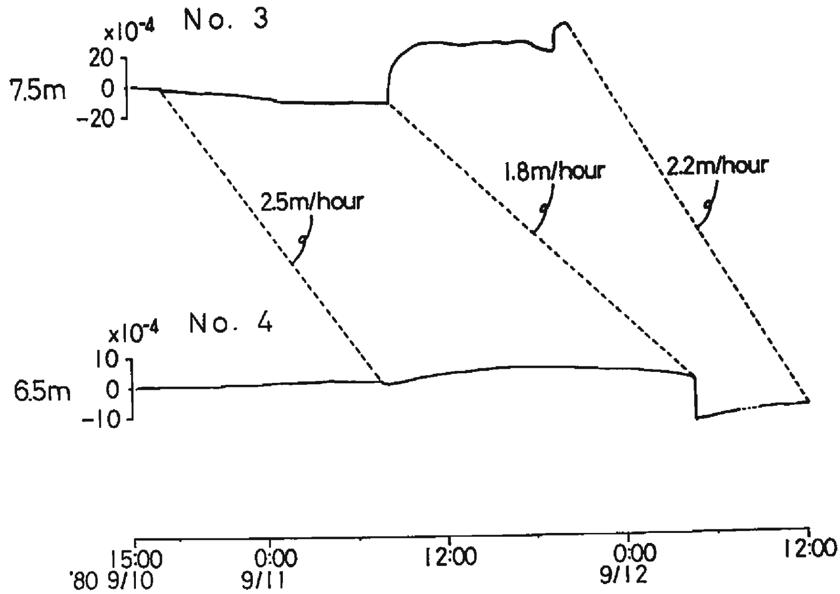


Fig. 13(b). Examples of the records of internal strain at site No. 3 and No. 4 in **Fig. 9** from Sep. 10 to Sep. 12, 1980; unit micro strain.

Table 3 (a). List of rupture velocity at the upper landslide at Irahara landslide area; strain rate was evaluated as the change during one minute just after the brittle fracture; unit micro strain.

	Onset time	Variation of strain	Mean rupture velocity
No. 7 17.5m	'80 9/11 9:10	-8×10^{-6}	3.6m/hour
No. 8 12.5m	9/10 22:45	-10×10^{-6}	
No. 7 17.5m	'80 9/11 18:01	-36×10^{-6}	5.0m/hour
No. 8 12.5m	9/11 9:53	-36×10^{-6}	

Table 3(b). List of rupture velocity at the middle landslide at Irahara landslide area; strain rate was evaluated as the change during one minute just after the brittle fracture; unit micro strain.

	Onset time	Variation of strain	Mean rupture velocity
No. 3 7.5m	'80 9/10 17:18	-63×10^{-6}	2.5m/hour
No. 4 6.5m	9/11 7:47	-24×10^{-6}	
No. 3 7.5m	'80 9/11 8:17	1599×10^{-6}	1.8m/hour
No. 4 6.5m	9/12 4:23	-1391×10^{-6}	
No. 3 7.5m	'80 9/11 16:51	scale over	2.2m/hour
No. 4 6.5m	9/12 11:27	scale over	

recorded an exponential phenomenon (a relaxation phenomenon). The relaxation time was a few hours. After abrupt change at 21:59 on Jul. 13, 1980, this phenomenon was not observed. Since a direction of strain change at 12.5 m at 5:09 on Jul. 13, 1980 was different from that at 21:59 on Jul. 13, 1980, it may be inferred that two slip surfaces existed. This phenomenon will be made clear after accumulation of data.

Next, the place of rupture occurrence, direction of its propagation and its velocity will be made clear on the basis of the observations of a landslide caused by typhoon 8013 in September 1980. Four internal strain meters, No. 3, No. 4, No. 7 and No. 8 in **Fig. 9** were set up in the landslide area, the range of which was determined by tiltmeters and extensometers, and recorded this landslide phenomenon. **Figure 13** illustrates a part of observations of each internal strain meter near the slip surface. The one to one correspondence was found out between the time when brittle fracture occurred and the time when the strain gauge was broken because of a landslide. A mean rupture velocity was determined by the time lag and the length between internal strain meters. The mean rupture velocity is presented in **Table 3**. Accumulated data indicated that in the area of No. 7 and No. 8, a rupture occurred at the lower slope than No. 8 and was unilaterally propagated to the upper slope at the speed of a few meters per hour. They indicated that in the area of No. 3 and No. 4, a rupture occurred near No. 3 and was unilaterally propagated to a lower slope at the speed of a few meters per hour. These velocities are faster than what Takada observed in the tertiary type landslide.[1]

The vertical velocity of propagation of subsurface displacement to ground surface is stated. As mentioned before, it was more than 1 m per minute. And there was only one observation, in which the velocity was less than 1 m per minute. **Figure 14** illustrates this phenomenon. The observations at five depths are shown. The onset time at 0.5 m, 1.5 m, 2.5 m, 3.5 m and 4.5 m were at 11:18, 11:16, 11:15, 11:13 and 11:13 on Sep. 11, 1980, respectively. Consequently, it was gradually late as the depth of gauge became shallower. These strain changes were not electric noise but resistance change of gauges because no scattering was observed before and after the onset time. The time lag was significant, since a crystal clock controlled the start of observation. The time lag of measurement of four gauges was 0.4 s. In this time, this lag is negligible, because the observed time lag was a few minutes.

Figure 15 shows a model to explain this phenomenon qualitatively. First PVC curves at 4.5 m (slip surface) and curves gradually as a subsurface displacement is propagated to ground surface. Finally the displacement reaches the ground surface. This mean velocity of propagation of subsurface displacement to ground surface was from 0.5 m to 1.5 m per minute, which was determined by the time lag and the length between internal strain gauges.

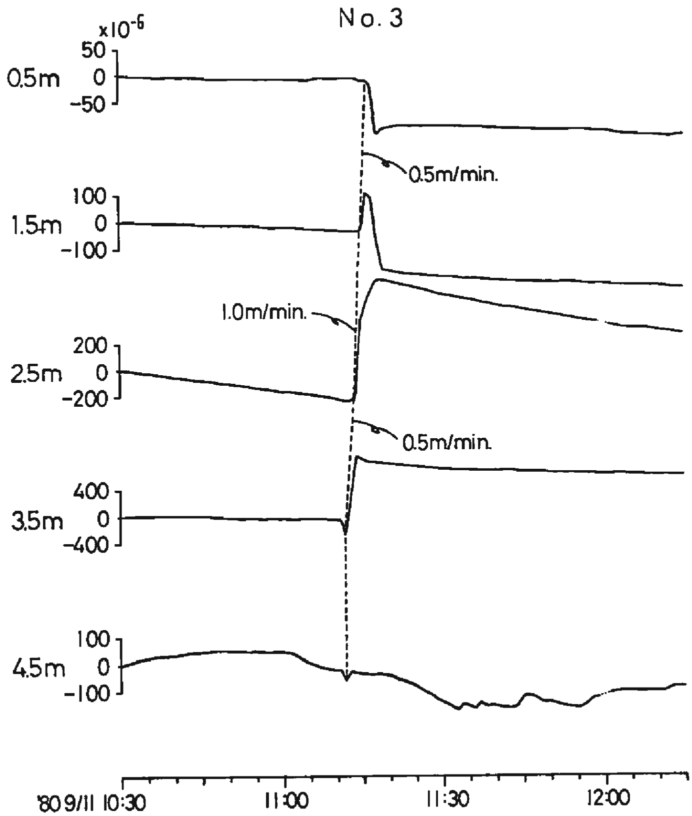


Fig. 14. Variation of the internal strain gauges at No. 3 shown in **Fig. 9** on Sep. 11, 1980; unit micro strain.

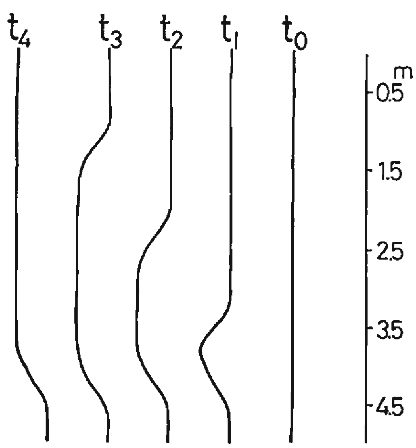


Fig. 15. Schematic model of propagation of subsurface displacement to ground surface.

Internal strain meters were mainly used for determining the depth of slip surface, because the accuracy of the time recording of the internal strains was rough. Since they were observed at an interval of one minute, an interesting phenomenon, which was as if PVC vibrated very slowly, was observed. **Figure 16** shows a part of the observations of the landslide at internal strain meter No. 12 in **Fig 9**, which was caused by typhoon 8019 in October 1980. Except vibrating very slowly, for example at 7.0 m and 8.0 m, there was no electric noise at any gauge (see **Fig. 16**). These records seem to indicate true displacements. However, the magnitude was about forty micro strains (peak to peak). The onset time and the time at peak value were 9:32, 9:56, 10:26 and 10:46 on Oct. 14, 1980, respectively. The very slow vibration of strain continued for about a quarter and an hour.

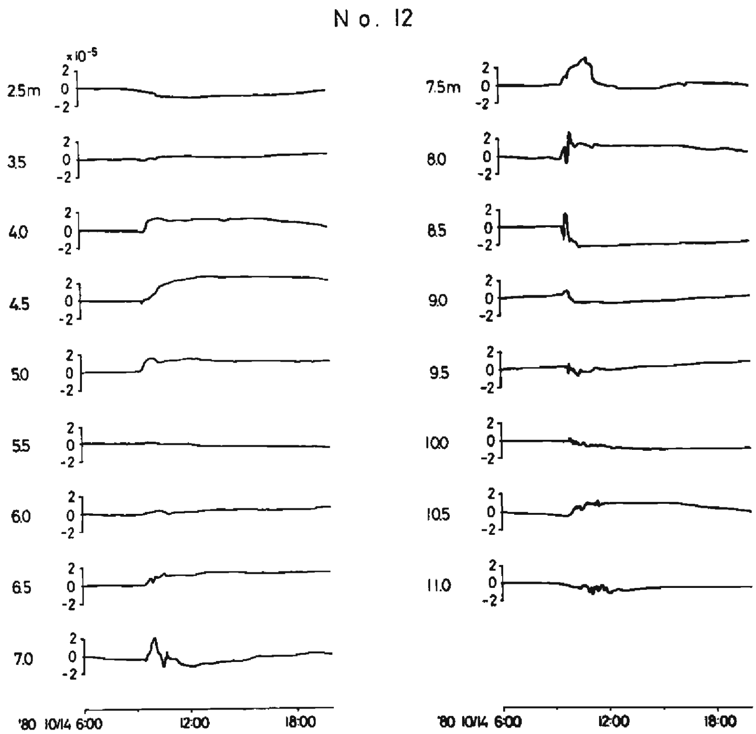


Fig. 16. Records of the internal strain at site No. 12 in **Fig. 9** from 6:00 to 20:00 on Oct. 14, 1980.

This phenomenon can be qualitatively explained as a very slow vibration propagating upwards at the recording depths (7.0~7.5 m), accordingly first PVC is straight, secondly convex, thirdly straight, fourthly concave, fifthly straight. **Figure 17** shows a schematic model to explain these observations qualitatively. To produce this phenomenon, there have to be two surfaces

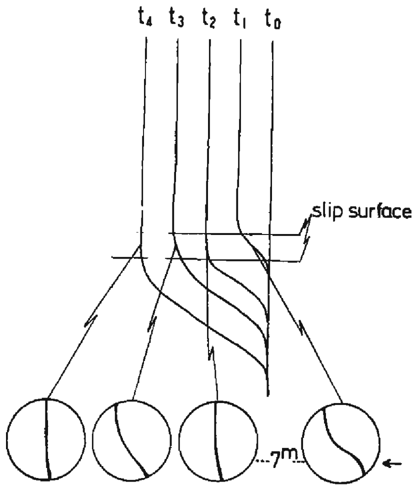


Fig. 17. Schematic model near slip surface. t_1 and t_3 are the time when landslide occurs at upper slip surface and t_2 and t_4 are the time when landslide occurs at lower slip surface.

which are several dozens of centimeters apart. First a landslide occurs at the upper slip surface and PVC is changed from straight to convex. Secondly it occurs at the lower slip surface on account of stress concentration and then this pipe is changed from convex to straight. Thirdly it occurs at the upper slip surface because of stress concentration and this pipe is changed from straight to concave. Fourthly it occurs at the lower slip surface because of stress concentration and this pipe is changed from concave to straight. At this time, the gauge records a very slow vibration phenomenon. This phenomenon which is that a failure zone (slip surface) shifts from one place to another, can be observed only when both time and depth are accurately observed. This is a new physical concept about landslide mechanism and an interesting problem. The author will analyze this phenomenon after accumulating data.

3.3 Kuki landslide area

Kuki landslide area in Tokushima Prefecture is situated in the Sanbagawa metamorphic belt. The bedrook is an argillaceous schist and a debris lies directly on it. This area was visited by typhoon 7617 in September 1976. The amount of rainfall reached 508 mm from Sep. 8 to Sep. 13, 1976, when a landslide occurred.

Figure 18 shows the location of instruments. The instruments except No. 25 were installed before September 1976. No. 25 was installed in January 1977 to determine the strain between No. 2 and No. 3, so there is no record for this time. **Figure 19** illustrates a part of the observations of extensometers. By the method mentioned before, the onset time was determined. The depth of slip surface was about 8 m. Accumulated data indicate that the time lag of producing a strain because of the difference of the depth of the slip

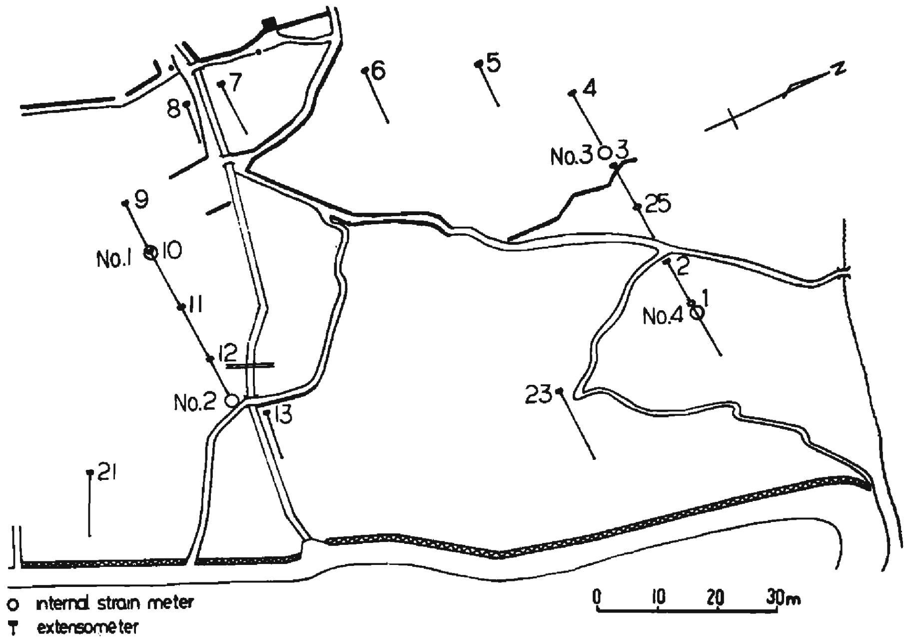


Fig. 18. Location of instruments at Kuki landslide area.

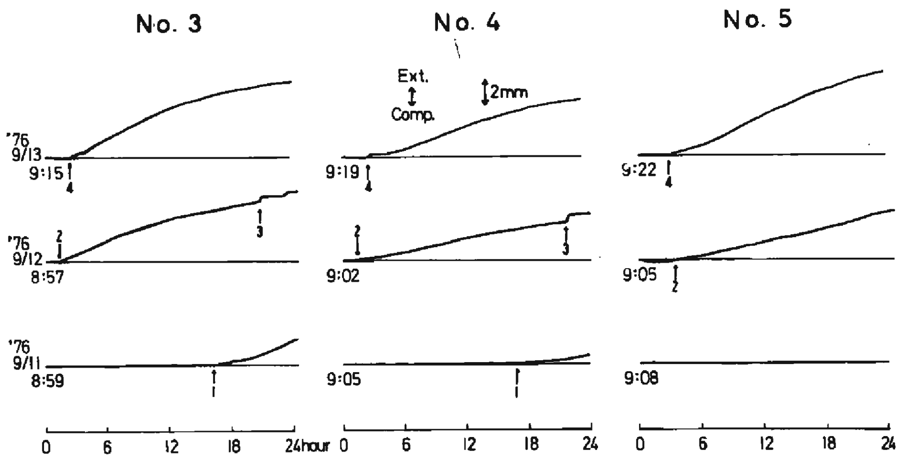


Fig. 19. Examples of the records of extensometers. Arrows show the onset time of displacement. The shown time are the starting time of the records.

surface was within a few minutes. This time lag was neglected as the first approximation. Excepting this onset time, known quantities were the length of the spans of extensometers, the length between extensometers, and the sense of displacement. Taking all these factors into consideration, the mean rupture velocity was calculated. **Table 4** shows the onset time and this velocity. In this area, a rupture occurred in the middle part of the slope and was unilaterally propagated upward. The velocity was between about 10 m and 200 m per hour.

Table 4. List of onset time and rupture velocity at Kuki landslide area.

Extensometer	Onset time	Mean rupture velocity	Onset time	Mean rupture velocity	Onset time	Mean rupture velocity	Onset time	Mean rupture velocity
No. 3	9/12 0:55	20.3m/h	9/12 10:33	19.6m/h	9/13 5:32	13.2m/h	9/13 12:03	91.4m/h
No. 4	9/12 1:49		9/12 11:26	24.4m/h	9/13 6:55		9/13 12:15	195.2m/h
No. 5			9/12 12:14				9/13 12:21	

4. Conclusion

In crystalline schist landslide areas, some of the physical quantities which define landslide mechanism were made clear by the observations of extensometers and internal strain meters. This is summarized as follows.

In subsurface displacements, the recods of internal strain meters made clear the existence of both creeping and abrupt landslide. The vertical velocity of propagation of subsurface displacement to ground surface was more than 0.5 m per minute. Maximum vertical velocity among the observations was more than 5 m per minute. The rise time observed by internal strain meter was about 3 hours and one observed by extensometer was somewhat over ten hours. The relaxation phenomenon observed by internal strain meter might be related to a coefficient of viscoelasticity. A failure zone (slip surface) shifted from one place to another and the direction of internal strain of a creeping landslide differed from that of an abrupt landslide. The phenomenon of very slow vibration of strain was observed. This phenomenon continued for about a quarter and hour. A rupture occurred at a spot of slope and was unilaterally propagated upward or downward at speeds which ranges from a few meters to 200 meters per hour, or bilaterally at the speed of a few meters per hour. Also, the phenomenon that the displacement depended on place existed.

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